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Method and device to cool an airflow

The invention is concerned with a method and a device to cool an airflow, for example as part of an air conditioning device.

With the usual air conditionings, a flow of used air is continuously removed to the outside and replaced by a flow of freshly supplied outside air of the same amount. During warm periods this freshly supplied air is cooled down before it is admitted to the building, for example to an inlet temperature of 16 °C.

This cooling down takes place with the common devices mainly using a compression cooling machine or using an absorption cooling device. Because this uses a lot of electrical energy, sometimes a pre-cooling is applied, in which the air that is supplied from the outside is pre-cooled in an indirect heat exchanger with the cooler removed air.

In Klima und Kalte Ingenieur 5/1977, page 239-242, an improvement of such a pre-cooling is shown, in which the air to remove for this heat exchange is first cooled down by nebulizing water in it, which subsequently partly evaporates. By this evaporation, said air to remove is cooled down, preferably to its wet-bulb temperature, and this cooled air is subsequently used for the pre-cooling of the fresh air. By this, the pre-cooling becomes much more effective, such that less energy is needed in the compression cooler. This energy saving may amount up to 38 %.

According to the invention an airflow is cooled down by indirect heat exchange in counter current with a second airflow, which second flow is cooled by evaporating water in it and the method is characterized in that the first flow, immediately after it has been cooled down by heat exchange, is divided into a first part that is used as a second flow, while water is being evaporated in it, and into a second part that is being removed as cooled air.

By the evaporation of water, the second airflow is cooled down to about its wet-bulb temperature. However, this wet-bulb temperature is for the cooled air considerably lower than for the same air before this air is cooled down, and therefore the first flow undergoes a heat exchange with a considerably colder airflow than with said method from Klima und Kälte Ingenieur, and the consequence is that the first flow according to the invention can be cooled down to a considerably lower temperature than with said known method.

In this manner it is possible to cool down the first flow to close above its dewpoint, irrespective of what the starting temperature of the first flow was.

In the drawing is shown :
Fig. 1 is a schematic representation of an embodiment of the device according to the method ;
Fig. 2 is a graph that shows the development of the temperature and the humidity level in an example of the method according to the invention in a device according to Fig. 1.
Fig. 3 and Fig. 4 are graphs that show the development of the temperature and the humidity level in an example of the method according to the invention in a device according to Fig. 5.
Fig. 5 is a schematic representation of a device according to the invention for air conditioning.

In Fig.1 is shown a simple embodiment of a device to perform the method according to the invention. At **1**, the first flow is supplied, for example freshly supplied air from the outside, which needs to be cooled. This air is led through the heat exchanger **2** and cooled down. Arrived at the left end **3** of the heat exchanger **2**, the first flow is split into a part that is transported by ventilator **4** as cooled air, and a part that is transported back to the heat exchanger **2** as a second flow by the valve **5** and the ventilator **7**. Before this flow is led through the channels of the heat exchanger, this air is moisturized by nebulizing water in it using the nebulizer **8**. Preferably, such an amount of water is nebulized, that the second flow is completely saturated with water and furthermore still an amount of water that is not vaporized remains in the form of a fine mist. By the heat exchange the temperature of the second flow rises and hence, a new amount of water may evaporate, such that the suspended droplets are converted slowly into water. This further evaporation of water has as a consequence that the temperature of the second flow rises less quickly than would be the case without these suspended droplets and the temperature difference between the second flow and the first flow thus rises in the drawing from the left to the right.

Because a part of the droplets settles before they may evaporate completely and because the total amount of water that can be suspended in the air as fine droplets, is limited, as a rule, all droplets will be disappeared before the right end of the heat exchanger is reached. Therefore, according to a preferred embodiment of the invention in the second flow, at at least one point between the ends of the heat exchanger, once again water is nebulized into the second flow. In Fig. 1 only two of such nebulizing devices **8** and **8'** are indicated, but it is clear that this number may be increased as the need exists. These sprinklers or nebulizers can be of any known type, but they are preferably chosen such that a part of the water that is as large as possible is dispersed as a very fine mist.

After the second flow has passed through the entire heat exchanger, it is removed by the drip catcher **9**, which catches a large part of the suspended droplets that are still present and which transports these droplets downwards.

Beneath the heat exchanger **2** a collector **10** is placed, in which all water is collected that settles from the second flow and from the mist filter. This water is transported back to the nebulizers **8** and **8'** by pump **12** and conduit **13**. The level in the container **10** is kept constant by supplying water at **11**, which is regulated by a float.

During warm periods, in which there is a need for cooling, the valve **6** in this device is kept closed and the valve **5** is kept open. During cold periods, in which there is no need for cooling, but there is a need to avoid the loss of heat with the ventilation air, the valve **5** is closed and valve **6** is opened. Furthermore, the nebulizers are not used. Hence, the air to be removed to the outside, enters in a known manner into indirect heat exchange with the air supplied from the outside, such that the fresh air is preheated and the used air is removed at about the temperature of the outside air. Hence, the device of Fig. 1 may also be used as a recycler.

Because the exchange surface is contacted with the evaporating water, it is possible that depositions thereon may occur. To prevent such, according to a preferred embodiment, these surfaces are manufactured of or coated with a material that is water-repellent, such that on this a closed film of water cannot be formed. Moreover, such a film would form an extra barrier for the heat flow, such that a water-repellent material is also useful in this respect. Surfaces,

manufactured from polyalkenes, such as polyalkene or polypropene or from impact-resistant polystyrene (ABC resin) appear to be very suitable and also relatively cheap.

The operation of the device according to Fig. 1 is explained in Fig. 2, which represents an i-x diagram (i=enthalpy and x=amount of water).

In this graph the temperature of the air (dry-bulb temperature) is as plotted on the right-hand scale. The upper abscissa scale shows the amount of water a partial water vapour pressure in mbar and the lower abscissa scale the amount of water as kg water per kg dry air.

The graph further shows straight diagonal lines that connect states with equal enthalpy and the enthalpy values are plotted on the diagonal scale at the right-bottom side. Also, in the graph are drawn the curves that connect the points with equal relative humidity, for example a relative humidity of 30 %.

When the state of the outside air that is supplied to the heat exchanger at **1** as a first flow, is indicated by point A (+32 °C, 0.011 kg water/kg dry air), then the wet-bulb temperature of that air is found by drawing a line through A, parallel to the lines for constant enthalpy up to the line of saturation. Hence, the wet-bulb temperature is given by point B and lies at about 21 °C.

The Fig. 2, 3 and 4 are drawn in such a way, that the isenthalps are straight and parallel lines. Because of this, it was not possible anymore also to draw all the isotherms horizontally (hence for equal dry-bulb temperature). When one should cool down air by evaporating water in it, starting in point A, until that air is saturated, one could not go below 21 °C and when one subsequently should use that saturated air to cool down another amount of air starting in A, one could not go beyond a temperature close above 21 °C.

However, according to the invention, starting in point A, air is cooled down first by indirect heat exchange to for example 17.5 °C. With this, the absolute level of moisture in the air does not change and hence one arrives in point C. At this temperature, a part, for example half, of the air is removed and the other half is further cooled down by evaporating water into it. With this, the state point of this second part shifts to point D with a temperature of about 16 °C.

Therefore, by the cooling in the heat exchanger, followed by the evaporation of water, a considerably lower temperature has been obtained than with direct wetting, and only by this it is possible to cool down the first flow to point C.

With the cooling down of the first flow, the enthalpy of that flow has decreased with 3.4 kcal/kg. Therefore, it is necessary that the enthalpy of the second flow (when it consists of precisely half of the first flow) increases with 2 x 3.4 = 6.8 kcal/kg. When the second flow is continuously kept saturated with water vapour, the point that reflects the state of this second flow, moves during the heat exchange along the curve DBE and the end state is the point E.

It is evident that this heat exchange is only possible when the temperature in D is lower than in C and therefore it is not possible to cool down the first flow with this heat exchange up to his dewpoint F, but only to a slightly higher temperature. As the point C closes in on the dewpoint F, the temperature difference between C and D that drives the heat transfer in heat exchanger, becomes also smaller and hence a correspondingly larger exchange surface is needed to transfer the necessary amount of heat.

In practice, a temperature difference between C and D of 1-4 °C and preferably of 1-2 °C appears to be still possible at acceptable dimensions of the heat exchanger. In that case the first flow is cooled down to 2-6 and preferably 2-3 °C above its dewpoint.

From the graph, it also shows that the dewpoint F is all the lower, the more point A lies more to the left and hence the absolute humidity of the air is smaller. Therefore, a lower temperature can be achieved, the more the water level in the air is smaller. Moreover, it does not matter what the initial temperature of that air is, because one will arrive in C upon cooling from a point directly above or directly beneath A. The only difference is that the point E will progress further or less further along the saturation curve to the right because then more or less water must be evaporated.

When because of very dry outside air the temperature of C becomes lower than desired, for example lower than 16 °C, the cooling can be decreased by evaporating less water into the second flow, for example by switching off one or more nebulizers **8'** or by reducing the part of the first flow that is transported back as the second flow. However, when because of a

large absolute humidity, point C cannot have a low temperature, as is desired, then the desired temperature can still be achieved by still further cooling down the air that is removed by C, for example using a compression cooling device or absorption cooling device. Also, with this, water will also be condensed.

Another method is to remove from the first flow a part of his humidity level before said flow is cooled down, for example by spraying in it a concentrated solution of lithium chloride (which subsequently needs to be regenerated) or with a regenerative rotating air dryer. By this, the dewpoint is lowered.

Anyway, in The Netherlands and in many other part of the world, only rarely circumstances occur in which the absolute humidity of the air is larger than 0.010 kg water per kg dry air, such that one can also content oneself that during a limited number of hours per year, the outlet temperature of the device is slightly higher than 16 °C.

The device according to the invention may be implemented in an air conditioning device in several ways.

One may only cool the freshly supplied air and supply it to the building and remove a corresponding amount of used air simply to the outside.

However, it is more favourable to cool down a flow of air that is to be removed from the building, use part of it to cool down the first flow of used air by evaporation of water, and transport this part back to the building. This provides an extra amount of cooling.

However, still more favourable is a device as schematically shown in Fig. 5, because this can be combined very effectively with a compression or absorption cooling device or with another usual cooling device, which extra cooling device only needs to be used when it is needed. This cooling device removes at once a part of the water vapour present in the air.

In Fig. 5,return air is transported at **1** from the building and this air is supplied at **22** to an indirect heat exchanger **23** and cooled down there in the same manner as in Fig. 1. The cooled air is divided at **24** into two parts. The first part is returned at **25** as cooling agent, humidified by the nebulizers **26** and **26'** and after heat exchange removed at **27**.

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The second part of the air to remove that was already cooled, is removed by the conduit **31**, humidified with nebulizers **32** and **32'** and used as cooling agent in a second heat exchanger **35**, in which the freshly supplied outside air is cooled. This fresh air is supplied at **34** and removed at **36**. The drawing schematically shows also a compression cooling device **17**, which can be switched on when the cooling in the heat exchanger **35** is deemed to be insufficient. The heat exchangers **23** and **35** are each provided with a container **28** with a water supply **29** and with a water pump **30** to transport water to the nebulizers.

For example, one may supply at **1** 10,000 kg/hr air at 25 °C and at an absolute humidity of 0.0087 kg water/kg air. This is subsequently cooled in the heat exchanger **23** to 14.5 °C. Of this 10,000 kg/hr, 5,000 kg/hr is saturated with water by the nebulizers **26** and **26'** (such that the temperature drops to 13 °C) and used to cool down the 10,000 kg/hr air to remove. This 5,000 kg/hr is subsequently at **27** removed at a temperature of 20 °C. The remaining 5,000 kg/hr is transported by a conduit **27** to a second heat exchanger and after humidification (such that the temperature drops to 13 °C) and heat exchange at **28** removed at 24 °C.

At **34** 10,000 kg/hr of air is supplied at 30 °C and with a water content of 0.015 kg/kg air. This air has a dewpoint of 20.2 °C and is cooled in the heat exchanger to 17.8 °C, in which at the same time some water condenses. This air, cooled down to 17.8 °C is further cooled down by the compression cooling device to 12 °C, while an extra amount of water condenses. Afterwards, the water content is about 0.0084 kg water per kg dry air.

From the supplied air an enthalpy has been withdrawn of 8.0 kcal/kg, of which 4.2 kcal/kg in the heat exchanger **15** and 3.8 kcal/kg in the compression cooling device **37**. Therefore, well over 52 % of the heat has been withdrawn in the heat exchanger **35**.

In this example a case has been described, in which it was assumed that from outside air with a high moisture content in the outside air a considerably larger part of the total cooling can be obtained in the heat exchanger **35**. At an air humidity of up to 0.0075 kg water/kg dry air, it is even possible to achieve a temperature of 12 °C without any use of a compression cooling device.

Fig. 3 shows the state changes of the air in the heat exchanger **23** from Fig.5 and Fig. 4 shows the changes in the heat exchanger **35** from Fig.5.

Point A is the state of the air to remove at **21** in Fig. 5, B is the state at **24**, **25** and **31** in Fig. 5, C is the state immediately after the first nebulizer **36**, respectively **32** in Figure 5, D is the state at point **27**, E that at point **33**, F that at point **34**, G that at point **36** and H that at point **38** in Fig. 5.

The apparatus depicted in Fig. 5 can also be used in cold periods as recycler by redirecting the different airflows, more in particular according to the dotted lines in said figure, while then of course the nebulizers are switched off. During these cold periods half of the freshly supplied air is supplied by each of the heat exchangers and this air is being heated there by heat exchange with the removed and used air.

The energy consumption of a compression cooling device is proportional to the number of hours the device is working, multiplied by the number of degrees C that the air must be cooled down by said cooling device. This product is designated as the cooling degree hours. This concept is defined in Recknagel-Sprengler, Taschenbuch für Heizung und Klimatechnik R. Oldenburg München, Wien (1974).

When the entire cooling is implemented with a compression cooling device using a recycler and is always kept at an inlet temperature of 16 °C of 8,99 hrs to 20,00 hrs, then for a complete year about 7,500 cooling degrees hours are needed.

Under the same circumstances, but with a cooling device according to Fig. 5 and when dividing the air to remove in two equal parts, only 120 cooling degree hours per year are needed. Thus, the number of cooling degree hours of the compression cooling device is only about 8 % of the number without the device according to the invention.

Because said compression cooling device according to the invention is only to cool air that is nearly saturated with water vapour, because of the condensation heat, the cooling energy needed is larger than for the cooling of air that is not saturated with water vapour. Hence, the energy consumption is larger than 8 % of this without the invention, i.e. 15-20 %. Hence, this saving is considerable.

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This is because, on the one hand a very intensive pre-cooling is applied, and on the other hand during the largest part of the year the compression cooling device does not need to be activated.

The remaining energy costs that are necessary to supply fresh air from the outside and to remove used air to the outside by a recycler, also arise with the method according to the invention and are about as large as with the known methods. However, these energy costs constitute for the known method a rather small part of the total energy costs, while they constitute with the method according to the invention a relatively large part and sometimes even the complete energy costs, i.e. then, when a compression cooling device is entirely abandoned.

Claims

1. Method to cool down an airflow by indirect heat exchange in counter current with a second airflow, which second flow is cooled by evaporating water in it, characterized in that the first flow, immediately after it has been cooled down by heat exchange, is divided into a first part that is used as a second flow, while water is being evaporated in it, and into a second part that is being removed as cooled air.

2. Method according to claim 1, characterized in that water is nebulized into the second flow before said flow enters the heat exchanger, while this nebulizing is repeated at least once during the heat exchange.

3. Method according to claim 1 or 2, characterized in that the supply of water to the second flow is arranged such that the second flow contains a mist of fine droplets in at least the largest part of the heat exchanger.

4. Method according to claim 1 or 2, characterized in that the first flow is cooled down to a temperature that is 2-5 °C higher than its dewpoint.

5. Method according to claims 1-4, characterized in that the second flow comprises 40 - 60 % of the first flow.

6. Method for air conditioning at least a part of a building, in which the air that is to be removed to the outside as a first flow, is cooled down with the method according to claims 1-5 by indirect heat exchange in counter current with a second flow, in which water is being evaporated, which second flow is obtained by dividing the first flow, after it has been cooled down, into a first part, which forms the second flow, and a second part, which is being used as a third flow to cool a fourth flow of air that is supplied from the outside by indirect heat exchange in counter current, while in that third flow, before and during said heat exchange, water is being evaporated.

7. Method according to claim 6, characterized in that water is being nebulized in the second and the third flow before these flows enter the respective heat exchangers, while this nebulizing during the heat exchange is repeated at least once.

8. Method according to claim 6 or 7, characterized in that the supply of water to the second and to the third flow is arranged such that these flows contain a mist of fine droplets in at least the largest part of the heat exchanger.

9. Device to cool a first airflow, which device is provided with an indirect heat exchanger, with a booster and conduits to transport the first flow through the heat exchanger, with a booster and conduits to transport a second airflow through said heat exchanger in indirect heat exchanging contact and in counter current with the first flow, and with at least a nebulizer to nebulize water into said second flow immediately before the supply point of said second flow to the heat exchanger, characterized in that the supply conduit for the second flow is a branch of the supply conduit for the first flow close to the exit site of the first flow from the heat exchanger, while the device is provided with means to regulate the volume ratio of the first and the second flow.

10. Device according to claim 9, characterized in that the device is further provided with at least a nebulizer to nebulize water into the second flow at at least a point situated between the supply point for the second flow towards its removal point from the heat exchanger.

11. Device for air conditioning, which is provided with a device according to claims 9-10 to remove an airflow to the outside while cooling, characterized in that it is also provided with conduits to transport the part that is not branched off from the first flow to a second heat exchanger, with at least a nebulizer to nebulize water in this remaining part and transport this part through the heat exchanger in indirect heat exchanging contact with a third flow of air that is supplied from the outside.

12. Device according to claim 11, characterized in that it is further provided with a usual compression cooling device to further cool down the cooled air from the second heat exchanger.

Figures

Figures 1 to 4 : are identical to publication. No translation is provided.